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Unbearable heat

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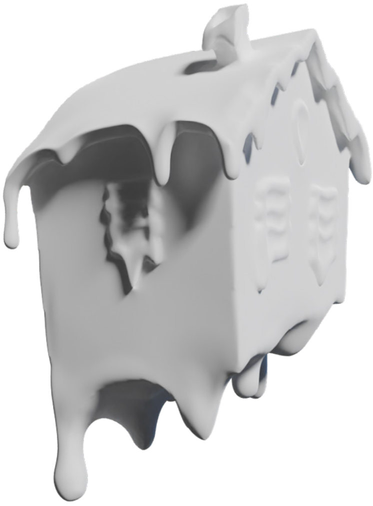
Acknowledgements: We would like to thank Liliana Narvaez for her support in this research.



Risk Tipping Points

Interconnected
Disaster
Risks

2023

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Abbreviations

AC	air conditioning
CDC	Centers for Disease Control and Prevention
EPA	Environmental Protection Agency
GDP	gross domestic Product
GHG	greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
NIH	National Institutes of Health
NIHHIS	National Integrated Heat Health Information System
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
WBGT	wet-bulb globe temperature
WBT	wet-bulb temperature
WHO	World Health Organization

On Shaikh Bhirkio Road, Fateh Chowk, Hyderabad, Sindh, Shahid holds a piece of ice to combat the intense heat of the day. The scorching weather demands a constant effort to stay hydrated, and the cold water provides some relief in the sweltering heat.
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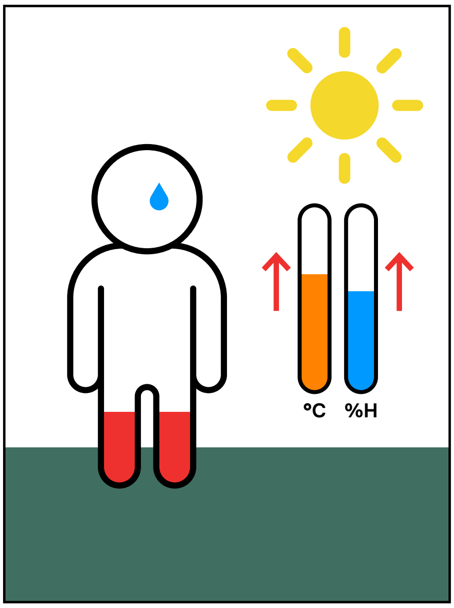
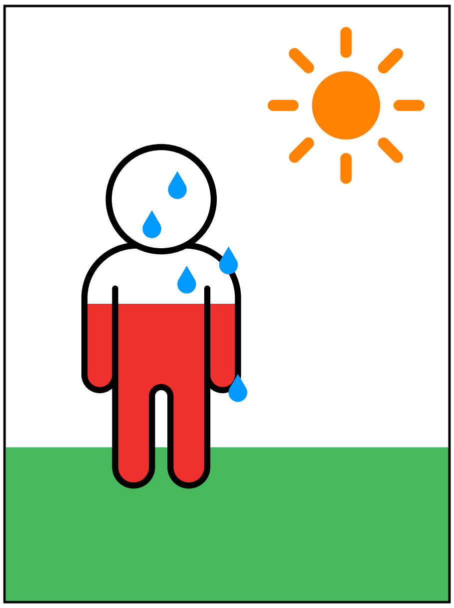
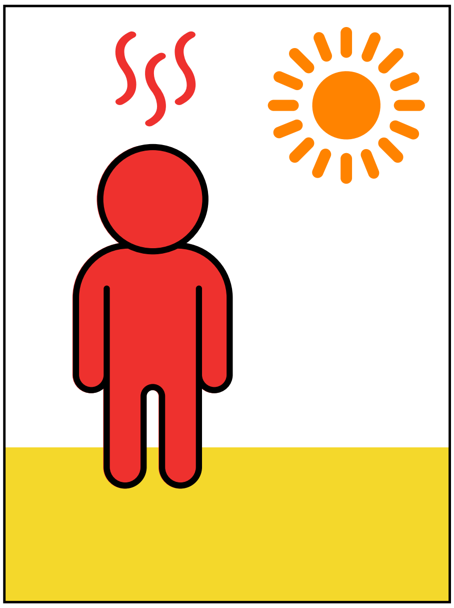
Graphical abstract



1. Increasing risk = Environmental conditions becoming increasingly hot and humid



2. Tipping point = 35°C wet-bulb temperature for longer than 6 hours



3. Tipped = Human body is unable to regulate internal temperature, leading to potential organ failure, coma or death

1. Introduction

Human-induced climate change is causing a global rise in temperatures. July 2023 set the record for the hottest month since data collection began in 1940 (Copernicus, 2023), as soaring temperatures brought unprecedented heatwaves to the United States, Europe and China. In 2023, the average global land and ocean surface temperature was 1.09°C higher than the pre-industrial average, with land surface temperatures reaching 1.59°C higher than average (IPCC, 2023). Extreme heat was already responsible for an average of 500,000 excess deaths annually in the last two decades, and this number is likely to increase as global temperatures rise. Humidity also plays an essential role in how heat affects the body (see Chapter 2), and the occurrence of extreme humid heat has doubled in frequency since 1979 (Raymond and others, 2020).

2. Risk tipping point

Extreme heat has severe consequences for human health. The average human body maintains a core body temperature of around 37°C and a skin temperature of 35°C. When the outside temperature increases, our bodies cool themselves down through various thermoregulation processes, including dilating blood vessels, decreasing metabolism or sweating (see **Figure 1**). Metabolism is the mechanism by which the body changes food into energy, which releases heat – thus, slowing down metabolism would decrease the body's temperature. Dilating blood vessels increases blood flow to the surface of the skin, away from the organs, and allows heat to be released through radiation (Holland, 2017). Sweat glands release sweat that usually evaporates off the skin. As sweat turns into water vapour, the energy required for evaporation is taken out of the air, thus cooling the skin and removing latent heat from the body. However, the evaporation of sweat is only effective when the outside air can hold more water vapour. If the air is hot and humid, then it is more difficult for sweat to evaporate, which is why humid heat is much more uncomfortable (Dean, 2022).

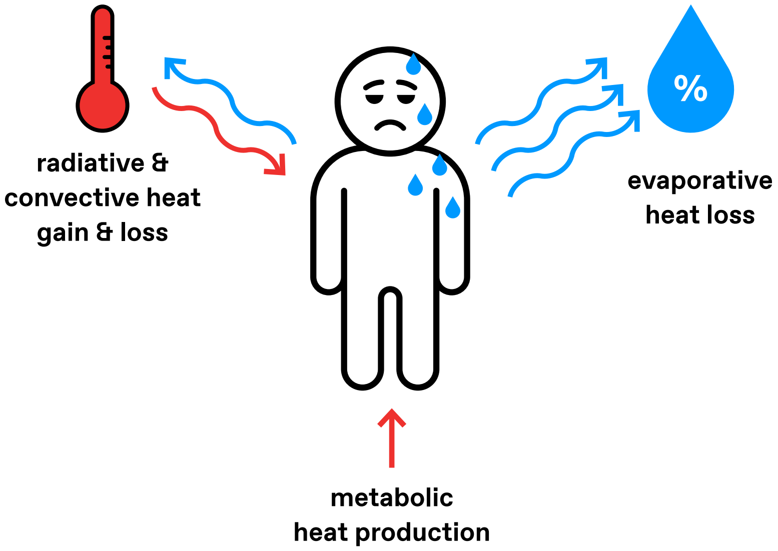


Figure 1: Simplified schematic of heat exchange between humans and their environment, adapted from Vecello and others (2023).

There are many different ways to measure heat. **Dry air** or **dry-bulb temperature**, measured by a thermometer, is the primary measurement reported in weather forecasts and which people most commonly refer to when referring to how hot or cold the air is. However, dry-air temperature alone is insufficient to understand how people experience heat. Since sweating and evaporative cooling play an important role, it is critical to also understand how temperature combines with humidity. **Wet-bulb temperature (WBT)** is the temperature to which a parcel of air can be cooled by evaporative cooling (Coffel and others, 2018). It is measured using a thermometer covered in a water-soaked cloth: as the water evaporates as much as it can in the given humidity levels, it lowers the temperature indicated on the thermometer, thereby accounting for the effects of evaporative cooling. At 100 per cent humidity, WBT is equivalent to the temperature measured by a standard dry-bulb thermometer but will be cooler if humidity is lower. For instance, a 35°C WBT can occur when the air temperature is around 40°C at 70 per cent humidity, or

45°C at 50 per cent humidity (Żuławińska and others, 2023). When the outside wet-bulb temperature exceeds the body's skin temperature of 35°C, then evaporative cooling becomes less effective and the body will accumulate heat (Coffel and others, 2018). As such, 35°C WBT represents "peak heat stress" for humans; the critical point at which heat becomes unbearable. Research suggests that being exposed to 35°C WBT for longer than six hours represents the survivable limit for humans (Sherwood and Huber, 2010). After crossing this risk tipping point, the prolonged exposure to these conditions will result in hyperthermia as the body overheats, leading to extreme health impacts (see Chapter 4.2).

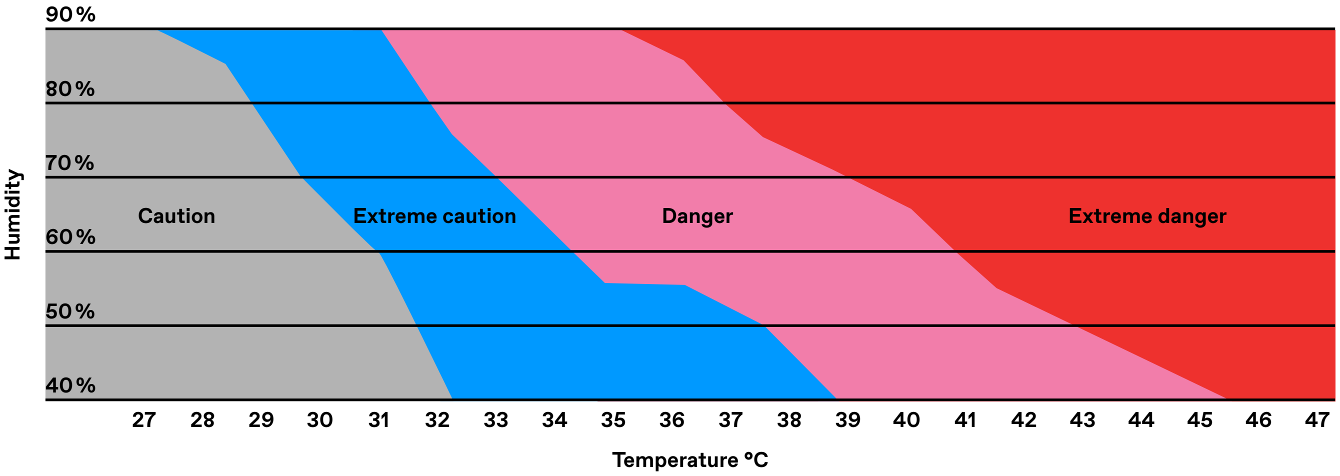


Figure 2: The combination of temperature and relative humidity approximates the impact of wet-bulb temperature on health, adapted from Meier and others (2023).

A thorough analysis of global weather station data indicates that by 2020 just two weather stations have recorded WBT of 35°C, one in the Persian Gulf and one in the Indus River basin, and only for brief periods of a few hours at a time (Raymond and others, 2020). However, other places have recorded worryingly close figures, with hotspots in east and north-west India, Pakistan, the Red Sea, the Gulf of California and the southern Gulf of Mexico (Raymond and others, 2020).

It should also be noted, however, that the 35°C WBT tipping point is a theoretical threshold based on the physiological principles outlined above, not empirical data. Some recent experiments suggest that the critical threshold may be as low as 31°C WBT, even for young and healthy adults (Vecellio and others, 2023). Indeed, many people feel the effects of heat well before it reaches 35°C WBT. A 2021 heatwave in British Columbia that led to over 600 registered heat-related deaths was measured at only 25°C WBT (Buis, 2022; White and others, 2023). Although the 2003 European heatwaves are estimated to have killed over 60,000 people, the maximum recorded WBT temperatures were around 28°C (Raymond and others, 2020). A recent assessment of the summer 2022 European heatwaves, estimated to have again caused over 60,000 heat-related deaths (Ballester and others, 2023), suggests a similar pattern, although certain parts of the continent such as northern Spain recorded a maximum WBT around 30°C. As such, some studies analyze not only the exceedance of a WBT threshold, but also include other factors into their measurements, such as physical acclimatization capability or the availability and efficacy of heat adaptation strategies and tools. The term "non-compensable heat stress" refers to the conditions under which a healthy human can no longer maintain a stable core body temperature without the use of external cooling mechanisms (Powis and others, 2023). Research has shown that since 1970, over 350 weather stations recorded at least one six-hour period of non-compensable heat stress (Powis and others, 2023).

Additionally, many other physical factors contribute to heat other than temperature and humidity. Solar radiation intensity and wind speed all also affect how the human body experiences heat and regulates these temperatures. For instance, higher wind speeds accelerate evaporative cooling and thus facilitate the cooling effects of sweating. Studies also show that exposure to higher levels of direct solar radiation increases thermoregulatory strain when exercising (Otani and others, 2019) and causes thermal discomfort in buildings (Kim and others, 2022). In contrast, staying out of direct solar radiation (in the shade) helps stay comparatively cooler and more comfortable. Since there are many factors that contribute to how humans experience heat, there are many ways to measure it beyond temperature and humidity. **Wet-bulb globe temperature (WBGT)** accounts for temperature, relative humidity, wind speed and solar radiation. This measurement uses WBT along with the other mentioned factors to indicate expected heat stress on the human body in direct sunlight for a specific location (NWS, 2023). However, this report focuses on WBT because people's tolerance of other mentioned indices can vary based on levels of clothing, activity or acclimatization. Using WBT as a measured threshold indicates a physical, thermodynamic limit for heat transfer that these type of adjustments cannot overcome (Sherwood and Huber, 2010).

2.1 Risk factors

The "human body" and "human physiology" referred to so far tend to be abstract, "ideal type" bodies modelled on young, healthy individuals. The experience of groups and individuals is highly dependent on the intersection of demographic factors, corresponding to different relative physiological risks. An intersectional approach is therefore essential when considering heat exposure, vulnerability and impacts. For example, advanced age influences vulnerability to heat more than any other non-modifiable risk factor (Benmarhnia and others, 2015; Meade and others, 2020). As such, older people are more likely to suffer during heatwaves and to experience heat stress at lower temperature thresholds. This is likely due to a combination of factors, including social isolation and age-associated chronic conditions (Meade and others, 2020; NIHHIS, 2023b). Additionally, children are less efficient at thermoregulation and have a higher metabolic rate than adults, making them also more vulnerable to the effects of heat (NIHHIS, 2023b).

Pre-existing conditions and chronic illness are also recognized as significant factors that heighten the risk during episodes of extreme heat. People with weakened heart or cardiovascular systems are particularly vulnerable, as the heart may not be strong enough to meet the demand required to release excess heat (NIHHIS, 2023b). People with diabetes also get dehydrated quicker and may also have damage to blood vessels or nerves that impact the ability to sweat. Cognitive impairment, such as Alzheimer's or dementia, can affect the ability to detect or communicate symptoms of heat illness or limit people's ability to take self-protective actions (NIHHIS, 2023b). Other health conditions that require people to take certain medications, such as antidepressants, diuretics or beta-blockers, can interfere with the ability to regulate heat or the awareness of symptoms (NIHHIS, 2023b). Pregnancy can also increase heat risk, as pregnant people tend to have elevated core temperatures in general (Zhang and others, 2017).

3. How did we get here?

3.1 Drivers

3.1.1 Atmospheric/ocean warming

Global surface temperature has already increased in temperature by 1.09°C above pre-industrial levels, with an average of 1.59°C warming over land surfaces (IPCC, 2023). As Earth's climate has warmed, heat extremes have become more frequent and severe (IPCC, 2023), and both days and nights are becoming hotter than usual (EPA, 2022).

3.1.2 Insufficient future planning

As heat extremes are on the rise, addressing them becomes ever more important. However, the pace of change is often not quick enough to keep up with the changing climate. One study found that, by 2050, 22 per cent of 520 major cities will experience climate conditions that are not currently experienced anywhere on the planet (Bastin and others, 2019). Many times, heat action plans and adaptation strategies are thought of only after a major heat extreme, and take years to implement. For instance, a county in Arizona published a Heat Action Planning Guide in 2017 outlining plans to build portable shade structures and create a heat warning system, but it took over five years to bring the recommended solutions to fruition (Loewe, 2023). Much effort is put into solutions that help in the short term, such as providing air conditioners, retrofitting infrastructure with cool surfaces or setting up cooling shelters, but it often comes at the expense of long-term adaptation or mitigation measures (Kingson, 2023). This particularly hinders the implementation of nature-based solutions such as planting trees. While being a great way to provide shade for communities, it takes time to grow them. In addition, changing climates impact the species' selection, so long-term planning is increasingly important.

3.1.3 Risk-intensifying land use

Urban expansion and densification contribute to reaching an unbearable heat risk tipping point due to the "urban heat island" effect, the phenomenon that urban areas are warmer than their rural counterparts. Urban growth has been shown to increase temperatures in cities by up to 5°C in some places (Chapman and others, 2017). This effect can occur as a result of many different factors. Cities often have built infrastructure from low-albedo materials, such as concrete and asphalt, that absorb and retain heat (Qian and others, 2022). These buildings and other structures can also create an urban canyon, where they block natural wind flow and the emission of heat energy into the atmosphere, trapping heat in the city. Densely populated urban areas also concentrate heat-emitting devices, such as cars or air conditioners, in a relatively small area (NIHHIS, 2023a). Importantly, development itself is not necessarily the problem, as it can be done in more efficient and resourceful ways, for example, by not disrupting important cold air corridors.

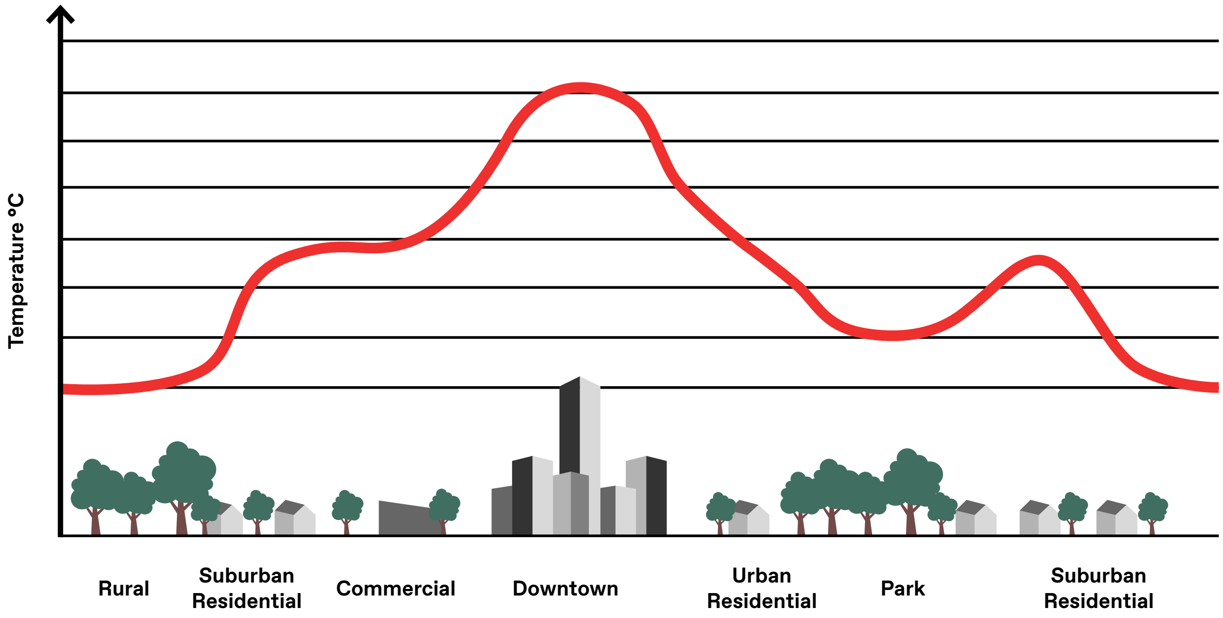


***Figure 3:** Urban heat island (source: Wikipedia, adapted from NOAA [2011])*

3.1.4 Living and working in at-risk areas

People's living and working conditions are an important factor for exposure to and risk associated with unbearable heat. This is especially dangerous in informal settlements that may be overlooked in heat stress exposure assessments (Ramsay and others, 2021). Many people live in poor-quality housing that is more susceptible to extreme heat and may lack access to certain services, such as energy or transport (C40 Cities, 2018). The inability to afford, or afford to run, an air conditioner also increases risk (Yardley and others, 2011); at the same time, air conditioning increases outdoor temperatures (Viguié and others, 2020).

Social isolation is also a major risk factor for heat-related deaths, while having friends, or being involved in group activities has protective effects (Yardley and others, 2011). People experiencing homelessness are also more likely to be socially isolated and economically disadvantaged and are therefore at an especially increased risk (Yardley and others, 2011). However, anyone can be at risk, even groups considered to be less vulnerable, depending on living and working conditions and behaviour (Sandholz and others, 2021).

Beyond living conditions and economic situations, some people are driven to the risk of unbearable heat by the kind of work they do. Some of the most affected professions are those that involve outdoor work, such as construction, farming, community services or street vending, or those working in in hot indoor environments, such as kitchens and factory workshops (Flouris and others, 2018). Workers typically do not have access to cooling services, such as air conditioning, water or shade, and often perform tasks that require intense physical exertion (NIHHIS, 2023b). Research indicates that people that work a single shift under heat stress conditions are four times more likely to experience heat strain, while 15 per cent experience kidney disease or injury (Flouris and others, 2018).

In May 2022, labourers work at a brick kiln factory on a hot summer day during a heatwave in Jacobabad, Pakistan.
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Additionally, gendered norms of living and working conditions influence the type and timing of work men and women do, as well as time and access to public and private spaces. This leads to different levels of exposure to or protection from heat. For example, a study focusing on the Dalit caste and Adavasi Indigenous women in north-central India found that women, unlike men, are expected to fetch and carry the water necessary to keep their families hydrated and cool, requiring trips even during peak heat times (Suchitra, 2023). Agricultural work is often gendered, with men or women more likely to be in fields in the heat depending on the cultural context and time of year (Holmes and Jones, 2011).

3.2 Root causes

3.2.1 Human-induced greenhouse gas emissions

Average and extreme heat are increasing on every continent due to human-induced climate change (IPCC, 2023). Even though greenhouse gas (GHG) emissions are often shown as an average over the entire world, extreme heat is location-specific and affects populations differently. For instance, the summer 2023 heat extremes in China were made 50 times more likely due to climate change, and those in North America and Europe were made at least 1,000 times more likely. Not only did GHG emissions make these events more likely, it also made them hotter. GHG emissions made the heatwaves 2.5°C hotter in Europe, 2°C hotter in North America and 1°C hotter in China (Zachariah and others, 2023).

3.2.2 Insufficient risk management

Heat is one of the deadliest hazards in the world, but is often considered an invisible threat or a silent killer since attributing deaths to heat is much more complicated than to a flood or an earthquake (WHO, 2023). Perceptions of heat risk vary widely, based on various structural, environmental, personal and social drivers that affect a person's understanding of risk and whether or not protective measures are implemented. For instance, people living in warm climates who are more acclimatized to heat may not take heat seriously as a threat (Hass and others, 2021). As such, the dangers of heat often go unrecognized until it is too late. This not only happens on an individual level, but also at an institutional or national level. For example, studies of European media have shown a tendency to focus on imagery suggestive of "fun in the sun" during heatwaves (O'Neill and others, 2023), rather than establishing extreme heat as a health emergency. Many places have not established heat action plans and lack heat early warning systems (Li and others, 2022; Eberle and others, 2022; Pillai, 2023). In fact, a detailed review showed that just 47 countries had implemented heat action plans as of 2021 (Kotharkar and Ghosh, 2022).

3.2.3 Inequality of development and livelihood opportunities

Research has shown the association between poverty and heat-related mortality in many countries (Gronlund, 2014; Benz and Burney, 2021). Low-income populations face 40 per cent higher exposure to heatwaves than people with higher incomes, likely due to a combination of location and access to heat adaptation measures (Alizadeh and others, 2022). Underserved or poorer communities may not even be aware of or have access to existing early warning systems (Guardaro and others, 2020). Urban inequalities and poverty have multiple impacts, not only on affordability of solutions, but also on living conditions. Space poverty in terms of tiny flats and lack of green spaces result in hotter surroundings, exacerbating heat impacts (Lo and others, 2022). Climate gentrification is likely to exacerbate these impacts further (Wang and others, 2023; Best and Jouzi, 2022). The development of climate-resilient infrastructure and green spaces that act as heat refuges in certain neighborhoods can often displace poor, minority communities to less climate-protected areas due to the increased housing costs (Kotsila and Anguelovski, 2023).

3.3 Influences

Reaching an unbearable heat risk tipping point would also have cascading effects that increase risk in other systems and may push them towards their own risk tipping points. Changing temperatures at rates outside of what can be reasonably adapted to can push systems out of the "safe operating space," and into conditions that the system is not equipped to handle. For example, extreme heat can increase the risk of **Accelerating extinctions**, since many species are not equipped to deal with rapidly increasing temperatures, and due to the large scale of heatwaves, mortality rates are often staggering. Recent heatwaves in Australia, for instance, caused the deaths of over 23,000 endangered spotted flying-foxes, or one-third of the national population (Mao, 2019), and around 1 billion marine creatures on the shorelines of Canada in 2021 (Einhorn, 2021). Endotherms (warm-blooded animals), and mammals in particular, share similar thermal limits as humans and thus similar health risks above the 35°C wet-bulb temperature threshold (see **Chapter 4.3**) (Sherwood and Huber, 2010). Although species have shown surprising ability to evolve and adapt to temperatures over multiple generations (Donelson and others, 2012), the increasing severity of short-term heat spikes is overwhelming adaptive responses in species such as birds, and thus extinctions may occur before they are able to adapt (Radchuk and others, 2019; Daly, 2021). Passing heat thresholds can lead to species die-offs and the increased risk of extinction can be more complex than individual deaths alone. Such changes in environmental and community structures reduce resilience across ecosystems as a whole, and raise the risk of secondary extinctions, opening the door for extinction cascades (Kehoe and others, 2021). Additionally, in response to increases in thermal extremes, species are moving their distribution ranges towards the Earth's poles to escape the heat, causing the collapse of existing interactions in the old habitat range and presenting often problematic interactions in their new habitat range (Stillman, 2019), which can threaten biodiversity and therefore accelerate extinctions even further.

Crossing unbearable heat risk tipping points will also have far reaching effects on risk in different systems beyond human and ecosystem health. For example, rising WBT change precipitation patterns and, in some mountain regions, reduced snowfall that the glaciers depend on to maintain their size, further accelerate the risk of **Mountain glaciers melting** (Tamang and others, 2020). As both temperature and humidity are important factors in snow production, there are wet-bulb temperature thresholds above which snow formation is limited (for example ~−2°C in the Austrian Alps (Olefs and others, 2010). As WBT rises in many parts of the world (Raymond and others, 2020), crossing such thresholds will reduce the important contribution of snow to the glacial mass balance and as a critical reflector of sunlight, due to the albedo effect, and accelerate progress towards glacial melting tipping points (Oerlemans and Klok, 2004).

Additionally, increasing WBT may also interact with groundwater and influence **Groundwater depletion**, though these effects may be conflicting. Higher air temperatures increase evaporation and therefore decrease soil moisture (Wu and others, 2020), but this may be mitigated somewhat by additional increases in humidity. Interestingly, groundwater depletion can also influence the occurrence of unbearable heat, as groundwater is extracted to the surface where it can more easily evaporate and increase the surrounding humidity (Ambika and Mishra, 2022). See the **Groundwater depletion** technical report for more details.

4. Where are we headed? Current and future impacts

4.1 The future we need to avoid

The risk of reaching an unbearable heat risk tipping point is already manifesting, and will only become more likely as the planet warms. If yearly emissions continue to increase, models project that by 2100, global temperatures will be at least 5°C warmer than the average from 1901–1960 (Lindsey and Dahlman, 2023). The occurrence of extreme humid heat has doubled in frequency since 1979 (Raymond and others, 2020). Currently, around 30 per cent of the world population is exposed to deadly temperature and humidity conditions for at least 20 days per year, and by 2100, this percentage could increase up to 74 per cent under a scenario of growing emissions (Mora and others, 2017).

Climate models suggest that WBT above 35°C will regularly be exceeded in the next 30 years in places like South Asia, the Persian Gulf and the Red Sea, and within 50 years for eastern China, South-East Asia and Brazil (Buis, 2022). Even in places where the WBT does not exceed 35°C, extreme heat is set to become one of the most significant impacts of climate change in the next decades. By 2070, annual exposure to WBT above 32°C could be five to ten times more likely, relative to 2020 (Coffel and others, 2018). The following section outlines the potential impacts that become more probable as we head down this trajectory.

4.2 Health impacts and loss of life

The primary impact of reaching a risk tipping point for unbearable heat is on human health. If the human body is unable to cool down its core temperature naturally, hyperthermia, or a core body temperature of 40°C, will occur. Hyperthermia can manifest in different ways, depending on a person's level of exposure, including fatigue, dizziness or fainting, heat cramps, heat exhaustion and, most severely, heat stroke (NIH, 2012). As core body temperatures rise, the proteins and cell membranes in a person's body begin to disintegrate, enzymes no longer regulate organ functions and organs begin to shut down (LeWine, 2023; Mellen and Neff, 2021). Sustained exposure to extreme temperatures can lead to organ damage, with the brain, heart, kidneys, intestines, liver and lungs at the greatest risk, and coma or death if the situation is not improved (Ebi and others, 2021).

Temperature extremes and heat stress can also worsen pre-existing chronic conditions, such as cardiovascular or respiratory disease (Ebi and others, 2021). They also increase the risk of adverse pregnancy outcomes, such as low birth weight, preterm birth and infant mortality (Zhang and others, 2017; Greenfield and Dickie, 2022). Increased sweating can also lead to dehydration and increased cardiovascular and kidney stress (Ebi and others, 2021). Beyond physiological impacts, heat can also cause psychological stress. Research shows that hot weather is linked to low performance on standardized tests, higher risk of occupational injuries and higher occurrence of emergency room visits for anxiety disorders, schizophrenia and dementia (Gianni and Gluck, 2021).

In this picture taken in May 2022, a woman uses a paper sheet to fan her child amid a power cut during a heatwave in Jacobabad, Pakistan.
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4.3 Ecosystem damage and biodiversity loss

Humans are not the only species affected by heat stress, as also shown previously (see **Chapter 3.3**). Higher temperatures lead to higher transpiration rates in plants, which means they require more water to survive (Saeed and others, 2023). Marine heatwaves are known to cause mass bleaching to coral reefs (Janzen and others, 2021) and kelp forests (Smale, 2020), mass mortality events in seabirds (Jones and others, 2023) and other marine animals (Cecco, 2021).

Many studies have focused on impacts to livestock, showing that cows and sheep have a heat stress threshold of around 30–34°C WBT (Barnes and others, 2004). Heatwaves can thus lead to mass deaths of farm animals. For example, at least 2,000 cows died of extreme temperature and humidity conditions in Kansas during a heatwave in 2022 (Polansek, 2022).

4.4 Livelihood loss

Extreme heat can also impact economic productivity and people's livelihoods, with direct effects on human work productivity. First, in some areas, as much as 40 per cent of daylight hours will become too hot to work, with potential losses of gross domestic product (GDP) greater than 20 per cent by 2100 (Kjellstrom and others, 2016). When people do need to work in hot and humid conditions, heat can decrease cognitive function. In India, higher WBTs are projected to lead to between 30 and 40 per cent decline in work performance by the end of this century (Koteswara Rao and others, 2020). Labour productivity losses may already be as high as $300 billion per year, most of which is from losses in heavy manual labour, such as agriculture and construction, concentrated in low- and middle-income countries (Parsons and others, 2021).

As mentioned in the previous section, the impacts of heat can be devastating for people dependent on agriculture or fishing, as heat is known for killing crops and animals. For example, higher WBTs affect agricultural livelihoods through decreased labour productivity in humans and decreased metabolism and growth patterns in livestock. Cows, for example, typically produce much less milk when heat-stressed (Belhadj Slimen and others, 2016). The effect on crops is somewhat more complex; though dry heat extremes are known to cause devastating reductions in yields for many crops, the effect of humid heat somewhat mitigates this effect by decreasing evapotranspiration and soil moisture loss (Ting and others, 2023).

4.5 Migration/displacement

Crossing a risk tipping point of unbearable heat could result in migration or displacement out of affected areas (Chazalnoël and others, 2017). For example, a longitudinal survey of migration patterns in rural Pakistan between 1991 and 2012 found a significant association between heat stress and the outmigration of men, most likely influenced by the negative impacts of heat on agricultural livelihoods (Mueller and others, 2014). One study in Australia found that 11 per cent of survey respondents intend to move away from their current place or residence because they feel heat-stressed (Zander and others, 2016). However, such findings are impossible to generalize, as migration is impossible to attribute to climate impacts alone (Chazalnoël and others, 2017).

The reality of mobility under unbearable heat is likely to take on a much wider diversity of forms that remain poorly understood. First, unbearable heat is not guaranteed to lead to outmigration (Issa and others, 2023). This is because people exposed and vulnerable to extreme heat risk may find themselves unable to leave despite their desire to do so. Others may also be unwilling to leave, despite the risks. Second, if people do move out of unbearably hot areas, it cannot be assumed that this will be a permanent choice. In some cases, individuals are likely to seek temporary solutions for the hottest times of the year on the assumption that even the most severe of heatwaves eventually ends. Third, many migrants may be moving into unbearably hot areas, exposing themselves to increased heat-related risk in their search for opportunities. This is especially the case for migration into cities, where newcomers often live in vulnerable conditions, but also temporary shelters and refugee camps. Long migratory journeys, such as through the Sahara Desert or across the U.S.-Mexico border, also expose many migrants to unbearable heat during their journeys.

5. The future we want to create

To assess solutions for avoiding risk tipping points, we must consider these key questions: Does the solution attempt to prevent negative system changes or focus on adapting to the changes? Does the solution work within the current system or drive a fundamental reimagining of the system? Answering these questions is critical for understanding how different actions advance risk reduction goals and yield varied outcomes, including potential consequences and trade-offs. To navigate this, we have developed the ADAT2 framework, which classifies solutions into four categories: Adapt-Delay, Adapt-Transform, Avoid-Delay and Avoid-Transform — see the **main report** for details

5.1 Avoid

Avoid actions alter the system to prevent crossing risk tipping points. The only real way to avoid crossing an unbearable heat risk tipping point is by limiting the amount of planetary warming by ceasing the burning of fossil fuels and limiting our GHG emissions. However, even with drastic emissions reductions, by 2100, global temperature may still increase by 2.4°C more than the average from 1901–1960 (Lindsey and Dahlman, 2023), and almost half of the world's population could be exposed to life-threatening climatic conditions for at least 20 days per year (Mora and others, 2017). A deep, rapid and sustained reduction of our GHG emissions is imperative to prevent even worse impacts from occurring in the future.

5.2 Adapt

Adapt actions reduce vulnerability and exposure to post-tipping point impacts and prepare for sustainable living within the new system. In order to adapt to reaching an unbearable heat risk tipping point, actions must be taken to reduce people's exposure and vulnerability. One method to adapt to increasing humid heat is acclimatization. This involves gradual exposure to hot conditions to create physiological adaptations, such as increased sweating efficiency, lower core body temperatures or increased skin blood flow (CDC, 2018). However, exposure to 35°C WBT for sustained periods of time are lethal even for acclimatized individuals (Sherwood and Huber, 2010).

Instead, actions can be taken to cool down and increase thermal comfort in the places where people are. Urban heat is strongly related to the quantity and type of buildings and other structures. Thus urban planning can strongly contribute to an overall risk reduction strategy (Fernandez Milan and Creutzig, 2015). For example, information on the spatial distribution of the heat risk across the city helps to plan and implement more targeted interventions. To this end, risk maps, which combine physical information such as topography, building types and densities, vegetation cover, with socio-demographic data and vulnerability profile are a helpful planning tool (Boumans and others, 2014).

A young boy carries home a battery-powered fan amid a heat wave and electricity shortage in Gaza city in July 2023.
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Specific cooling strategies can be undertaken through either active or passive cooling. Active cooling relies on energy-consuming devices like electric fans and air conditioners. Electric fans help circulate air and encourage evaporative cooling, but their effectiveness diminishes if the relative humidity increases above 70 per cent (Penman and others, 2022) or if temperatures rise beyond 35°C (Morris and others, 2021; WHO, 2023). Air conditioners (AC) are an effective tool for combatting heat (Woetzel and others, 2020), and in many settings, AC will be necessary and life-saving. However, widespread AC-use poses significant challenges. First, AC-use during heatwaves can lead to peaks in energy usage that risk overloading energy grids, the failure of which would lead to life-threatening situations (Sherwood and Huber, 2010). ACs also contribute to greenhouse gas emissions due to their energy-intensive nature and hydrofluorocarbon (HFC) refrigerants (Denning, 2022). Additionally, widespread AC use can exacerbate urban heat island effects, raising street level and night-time temperatures (Lundgren and Kjellstrom, 2013). AC thus appears as a fundamentally maladaptive solution to unbearable heat; at best, delaying the negative impacts of heat and redistributing them unequally – even if it remains essential in some contexts such as hospitals.

Passive cooling, on the other hand, does not rely on electrical energy to function. These interventions include building materials and design or green infrastructure. For instance, windcatchers have been used for centuries to cool houses, often with the additional use of evaporative cooling by adding green-blue infrastructure in courtyards. They are applicable to modern architecture and different regions (Sangdeh and Nasrollahi, 2022). High-albedo materials, such as reflective or white coatings on buildings or pavements, can reduce air temperatures in urban spaces (Santamouris and others, 2007) by reflecting solar energy rather than absorbing it. However, they do increase reradiation of solar energy onto pedestrians (Taleghani, 2018). For outdoor spaces, tree planting and vegetation on available surfaces can be a useful, low-tech and low-cost adaptation that many cities can take to create shaded areas and encourage evaporative cooling (Moss and others, 2019). In a global meta-study, shade provisioning was identified as the most important contribution of trees to human thermal comfort, while evaporative cooling contributed relatively less. The degree to which shade provisioning helped, though, greatly depends on the total surface area that is shaded by trees and the density of foliage, as it directly influences how much solar radiation is transmitted through the tree crown (Rahman and others, 2020). The cooling effect of water bodies can also be more strategically used in city planning. Water bodies have been shown to have a cooling effect of up to 2°C, which may also benefit areas distant to the water body if wisely planned by, for example, avoiding physical barriers and establishing more green areas around the water body (Hathway and Sharples, 2012; Chun and Guldmann, 2014).

In the context of humid heat, measures can also be implemented which reduce humidity indoors. Certain architectural configurations, such as the position and orientation of buildings, shape and design of roofs or balconies, location and types of windows, and even furniture arrangements, can all influence the movement of air within a building (Prianto and Depecker, 2003) and mitigate the accumulation of humid heat to increase thermal comfort.

Additionally, actions can be taken to help people to get out of the heat. One way to do this is to shift active hours away from the hottest portions of the day. Some countries in the Persian Gulf, such as Saudi Arabia and the United Arab Emirates, already prohibit outdoor work from noon to 3 p.m. during the summer months (Economic Times, 2022). The traditional Spanish siesta, a long midday break that usually includes a large meal and a nap, is starting to make a comeback and spread to other European countries as a way to beat the heat (Chilukuri, 2023). Research suggests that to compensate for labour losses due to heat, a global average shift of around six hours will be required by 2090 (Takakura and others, 2018). Additionally, shifting working hours can come with its own issues, including impacts on sleep quality and circadian cycles, issues with local noise ordinances and increased need for nighttime lighting (Parsons and others, 2021). Migration out of heat-affected areas can also be seen as an adaptation option, if it is voluntary and increases people's opportunities or capacities. As mentioned previously, many individuals are likely to seek temporary solutions for heat during the hottest times of the year. For instance, Jacobabad, Pakistan is often considered one of the hottest cities on Earth and has crossed over the 35°C WBT threshold twice since 2010 (Greenfield and Dickie, 2022). During the summer months, many residents migrate to nearby mountain towns, such as Quetta, to escape the heat (Tunio, 2022). However, this option is not always available to everyone and carries its own consequences (see Chapter 4.5).

Last, actions can be taken to provide education and support to people dealing with unbearable heat. Especially as the impact of heat often goes underrecognized, heat early warning systems and action plans are increasingly important, including timely notification of heat events, predicting heat-related public health outcomes and effectively communicating prevention responses to the public (Lowe and others, 2011). Additionally, social support and policies to reduce heat health inequality are essential, such as setting up public cooling centers and providing transportation to access them or improving worker's protection laws (Kearl and Vogel, 2023). Similarly, improved access to healthcare and health services, including sufficient infrastructure and capacity within healthcare facilities, could help reduce the impacts of heat-related illnesses (Kearl and Vogel, 2023).

A woman cools off with cold bottles of water, distributed by the Hellenic Red Cross organization near the entrance of the Acropolis archeological site in Athens on 20 July 2023, as the country is hit by a new major heatwave.
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Enhancing neighbourhood support networks and social capital during extreme heat can also significantly reduce health impacts (Wolf and others, 2010), as neighbours are encouraged to check in on each other and identify health issues before they become severe. New York City's "Be A Buddy" programme, for instance, matches at-risk individuals with neighbourhood volunteers who check in on them during severe weather events (Kearl and Vogel, 2023). Additionally, remittances play an important role in households' abilities to adapt to climate change. Households with income constraints in Mexico often use income from U.S. remittances to invest in cooling devices (Randazzo and others, 2023).

5.3 From Delay to Transform

Whether we take actions to adapt to or avoid the oncoming unbearable heat risk tipping point, these actions can only take us so far. Since the root causes and drivers of the problem are so diverse, it will require an equally diverse solution package of actions addressing multiple angles at once. For instance, increasing shade and ventilation in cities is a great first step that ideally should be combined with social protection and heat action plans to ensure that all aspects of heat impacts are addressed. However, solutions that do not address the underlying root causes and drivers of the risk tipping point are insufficient. If we only implement solutions to address the impacts of heat, such as installing air conditioners or shifting working hours, these actions will face constant pressure from the behaviours, values and systems that have created the problem in the first place. As such, these adapt and avoid solutions must be taken up not only to **delay** the tipping point or its worst impacts, but they need to work towards **transforming** the systems that created this risk tipping point in the first place.

For example, planting trees and other plants is a good way to reduce heat in cities, but it does not fundamentally transform the urban system and our relationship with nature that is exacerbating the problem of heat. Instead, a more transformative approach would be to rewild our cities by allowing nature and society to coexist for mutual benefit. One such approach is to create “sponge cities” designed with permeable pavements and green spaces to increase shade and evapotranspiration to mitigate heat impacts, while also absorbing rainwater to prevent flooding and recharge groundwater, and provide habitats for wild species to live and roam (Simon, 2022).

Additionally, creating programmes for checking on neighbours and providing access to health services can help reduce heat-related mortality. Transforming our society towards a system that encourages individuals to show each other trust, respect, empathy and compassion for others will make it so that caring for neighbours is the default. Caring for and supporting those around us holds the power to bring about meaningful change in the world that reduces risks for all and saves lives. Also, we may need to transform to adjust our expectations for services during the hottest parts of the day or year in order to consider the well-being of workers operating in those conditions.

Finally, the impacts of heat will not affect everyone equally. As the planet warms and we approach unbearable heat risk tipping points, certain levels of adaptation will become necessary for survival. However, many of the solutions listed above assume a degree of wealth and resources to implement that some people, neighbourhoods, cities or countries may not have. Additionally, many of the existing studies on urban heat have only focused on formal settlements, leaving informal settlements, which contain 30 to 85 per cent of some cities’ populations, largely unattended (Baruti and others, 2019). Additional care must be taken to ensure solutions to address unbearable heat apply to everyone, not just to those with means. This will require large-scale changes on a societal level to ensure protections for the most vulnerable and a complete transformation of our global system with a commitment for equity and justice.

The metro passes by a green corridor in Medellin, Colombia, in June 2021. © Joaquin Sarmiento / AFP.

6. Conclusion

We are headed towards a risk tipping point of unbearable heat, as rising temperatures and humidity levels around the world will soon surpass the limits of what our human physiology is able to withstand. This phenomenon is a direct consequence of climate change, driven primarily by human activities such as the burning of fossil fuels, deforestation, and other industrial processes. The consequences of rising WBT are far-reaching and multifaceted, and will affect various aspects of our environment, society and health.

Though we have identified a risk tipping point at 35°C WBT for over six hours, it is crucial to understand that the vast majority of people will experience health impacts at far lower thresholds. This is why global action to stop climate change and mitigate its effects are so urgent; every increase in warming increases the chances of catastrophic impacts. Fortunately, we have the benefit of seeing the risk tipping point ahead of us and can choose to turn away from the brink. To effectively address rising WBTs around the world, a comprehensive approach is required that can address the root causes of the problem in an interconnected way. Many solutions will be needed, ideally working together as a package, to address all aspects of the problem associated with rising humid heat. These solutions can also provide other co-benefits that reinforce each other, or even help prevent crossing other risk tipping points as well. Furthermore, we have an urgent global responsibility to end climate change and the burning of fossil fuels, a pressing need to make people's living conditions less heat-prone and adaptable to various climate conditions, and an obligation to assist those who are most vulnerable to the impacts of heat. Only then can we ensure that no one, in the present or the future, has to live in the unliveable.

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Cover Image Credit: Labourers are silhouetted against the sun as they work at a brick kiln factory on a hot summer day during a heatwave in Jacobabad, in southern Sindh province, in May 2022.
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https://doi.org/10.53324/HIAD3287

e-ISBN:978-3-944535-85-2
e-ISSN: 2304-0467